E7.3 10827
CR-133332

ALL-DIGITAL PRECISION PROCESSING OF ERTS IMAGES

(E73-10827) ALL-DIGITAL PRECISION PROCESSING OF ERTS IMAGES Interim Report, Aug. 1972 - Jun. 1973 (International Business Machines Corp.) 44 p HC $4.25 CSCL 05B G3/13
N73-27299
Unclas
00827

Ralph Bernstein
International Business Machines Corporation
18100 Frederick Pike
Gaithersburg, Maryland 20760

July 1973
Interim Report for Period August 1972 – June 1973

Prepared for

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland 20771

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

44 p.

ALL-DIGITAL PRECISION PROCESSING OF ERTS IMAGES

Ralph Bernstein
International Business Machines Corporation
18100 Frederick Pike
Gaithersburg, Maryland 20760

July 1973
Interim Report for Period August 1972 - June 1973

Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle All-Digital Precision Processing of ERTS Images		5. Report Date July 1973 6. Performing Organization Code
7. Author(s) Ralph Bernstein		8. Performing Organization Report No.
9. Performing Organization Name and Address International Business Machines Corporation 18100 Frederick Pike Gaithersburg, Maryland 20760		10. Work Unit No. 11. Contract or Grant No. NAS 5-21716
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771 Technical Officer: Frederick Gordon		13. Type of Report and Period Covered Interim Report for Period August 1972 - June 1973 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

ERTS-1 MSS and RBV data recorded on Computer Compatible Tapes have been analyzed and processed, and preliminary results have been obtained. No degradation of intensity (radiance) information occurred in implementing the geometric correction. The quality and resolution of the digitally processed images are very good, due primarily to the fact that the number of film generations and conversions is reduced to a minimum. Processing times of digitally processed images are about equivalent to the NDPF electro-optical processor. The next phase of the effort involves the completion of geometric and radiometric analyses, the production and evaluation of annotated MSS and RBV images, error and configuration analyses, and further studies of the utility of the SSDA algorithm and of filtering techniques.

17. Key Words (Selected by Author(s)) Digital image processing, ERTS image processing, precision image corrections Precision CCT Generation	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 37	22. Price*

PREFACE

This constitutes the second interim report for Contract NAS5-21716. It is the objective of this contract to develop an all-digital system for precision geometric and radiometric correction (Scene Correction) of ERTS RBV and MSS images and to use that system to actually perform corrections upon selected ERTS images. This report describes the work which has been completed since July, 1972 and outlines the efforts required to complete the contract.

Technical results are reported for studies of reseau detection/migration, the use of the SSDA algorithm in GCP experimentation, the use of APL programs to estimate the accuracy of several approaches to MSS geometric correction, and intensity modification experiments. Samples of precision processed images are included, and current estimated processing times are tabulated.

Remaining tasks include the completion of annotation requirements, the completion of RBV geometric and radiometric analysis and programs, the production of MSS and RBV images and their evaluation, MSS and RBV error analyses, an investigation of the utility of the SSDA algorithm in GCP location, a system configuration analysis, and a study of filtering techniques as an alternative to nearest-neighbor replacement and bilinear interpolation. The final outputs of the all-digital system developed for this project will be recorded on film and delivered to NASA for comparison with corresponding NDPF outputs.

Preliminary conclusions are stated on the subjects of preservation of radiometric information, preservation of resolution, mapping accuracy, operational feasibility, throughput, and feasible technology.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 INTRODUCTION

This report describes the work accomplished since August, 1972 under Contract Number NAS5-21716. Work performed prior to August, 1972 has been reported in Reference 1. The purpose of the contract is to implement an all-digital system for precision geometric and radiometric correction of ERTS RBV and MSS images and to use this system to apply corrections to selected ERTS images.

During this reporting period, MSS images have been geometrically and radiometrically corrected, and samples of precision processed images have been produced and evaluated. Studies are reported on reseau detection/migration, GCP experimentation, mapping functions and accuracies, intensity modification, and processing times.

Plans for the remainder of the contract period include the production and evaluation of RBV and MSS precision processed images, related error analyses, and other studies. Both the accomplishments and the plans are discussed in the following sections.

2.0 WORK ACCOMPLISHED

Due to the shutdown of the RBV shortly after ERTS launch, processing priority during the current reporting period for this contract was given to the MSS data. With the exception of the reseau detection/migration study, all processing performed was on MSS data, although an APL program which simulates the RBV processing system has been written and work is now being done on the improvement of this program. Preliminary programs have been written and are being improved to accomplish geometric and radiometric correction of MSS imagery and two scenes have been processed: ID No. 1002-18134 (Monterey) and ID No. 1062-15190 (Chesapeake). The Sequential Similarity Detection Algorithm (SSDA) was applied to MSS Ground Control Point (GCP) detection. Estimates of current processing times were made. The work performed in each of these areas is discussed below.

2.1 Background

This investigation deals with applying digital techniques to the processing of ERTS-1 image data, and in particular, to the Precision Processing (Scene Correction) of ERTS-1 data. The objective of the investigation is to geometrically correct an ERTS image to a UTM projection, maintain or correct the sensor radiometry (intensity), fully annotate the data, record the results on computer compatible tape (CCT) and on film, and evaluate the results.

2.1.1 Current NDPF Approach

The NASA Data Processing Facility (NDPF) has two image processing modes: Bulk Processing (System Correction) and Precision Processing (Scene Correction). Generally speaking, the System Corrected mode provides the best resolution and image quality, while the Scene Corrected mode provides the best geometry useful for topographical feature location.[2]

System Correction Processing provides some degree of geometric correction using, for example, previously measured RBV reseau position data or attitude data determined from the ERTS Attitude Measurement System, and altitude and position data from ephemeris sources. Scene Correction uses Ground Control Point (GCP) information to determine the residual geometric errors and the CRT Scanner/Printer generates a product with improved precision. The predicted NDPF mapping accuracies for these processing modes are shown in Table 1.

Table 1. NDPF Performance (Predicted)

	Positional Mapping Accuracy (Meters, RMS)		Registration Accuracies (Meters, RMS)	
Processing Mode	RBV	MSS	RBV	MSS
System Correction (240 mm, 9-1/2")	780	757	336	159
Scene Correction (240 mm, 9-1/2")	92	242	118	154

Recent results[3] have shown that a Scene Corrected image will have very good geometric quality (adequate for about 1:250,000 scale). However, the nongeometric quality (i.e., radiometry and resolution) is adequate for 1:500,000 to 1:1,000,000 scale. This contrast between geometric and nongeometric quality is due to the degradation of radiometric quality in the conversion of the digital (MSS) or analog (RBV) sensor data to film, the use of several film processing stages, reconversion to analog form, and the generation of two additional film stages (see Figure 1).

2.1.2 Digital Image Processing Concept

A digital image is a two-dimensional array of numbers, whose x- and y-address relate to line number and picture element position along a line,

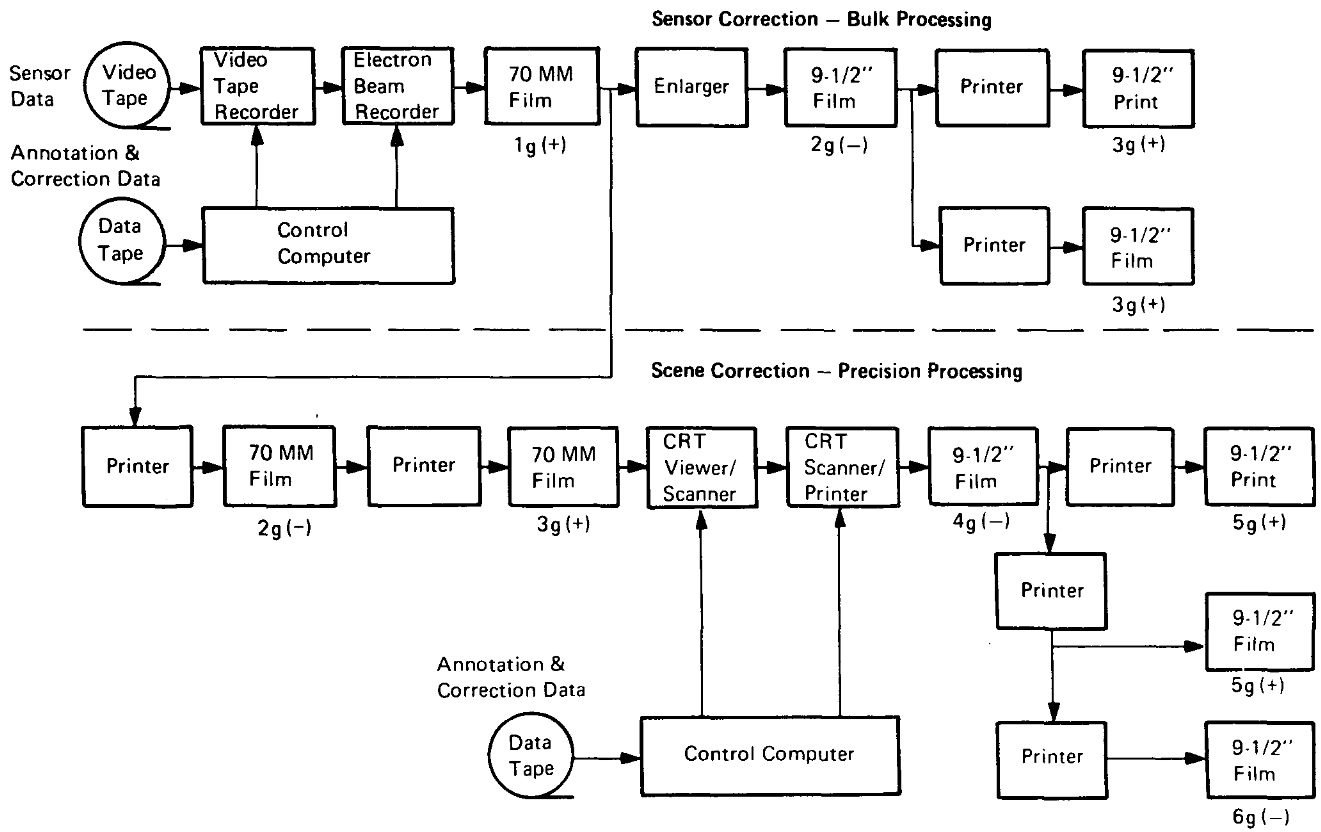


Figure 1. NASA Data Processing Facility Configuration and Data Flow

respectively, and z relates to pixel intensity (which is proportional to scene radiance for ERTS). This is shown in Figure 2. Geometric correction involves repositioning the pixels from where they are to where they should be in order to achieve the desired geometric correction or projection. Radiometric correction involves changing the intensity value, z, from what it is to what it should be. The desirable attributes of this concept are the repeatability and accuracy that can be achieved. An obvious disadvantage is the processing times that can occur if efficient computational algorithms are not used.

2.1.3 Investigation Approach

Based upon previous analysis and experimentation[4,5], it has been felt that good radiometry and geometry can be achieved by digital image processing, which minimizes the number of film generations and data conversions. Figure 3, in which the symbol ng($\pm$) indicates an nth-generation positive or negative film print, shows the approach used by IBM to achieve Scene Correction of ERTS images. The sensor data, on computer compatible tapes (CCT's), are read into a digital computer. Annotation and correction data, also on tape, are used for providing the necessary support data (see Section 2.2). The geometric and radiometric corrections are implemented through software, and standard annotation data is combined with the processed image data to generate another CCT containing a scene-corrected image. This tape data is then read into a film recorder, which maintains the positional (x and y) relationship and uses the intensity (z) to modulate a light source which exposes the film.

The advantage of this approach is that the final product is a second-generation photo and involves no unnecessary data conversion stages. It should be noted that in the case of the MSS, the data is digitized in the spacecraft, transmitted to ground, and handled prior to processing in a digital form.

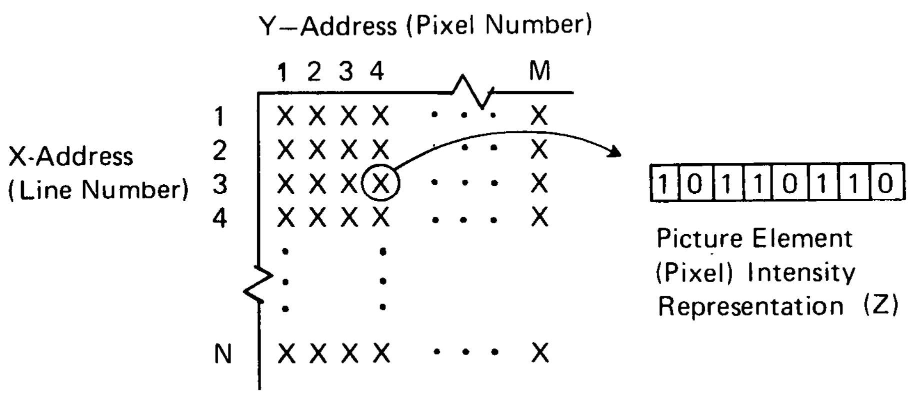


Figure 2. Digital Image Processing Convention

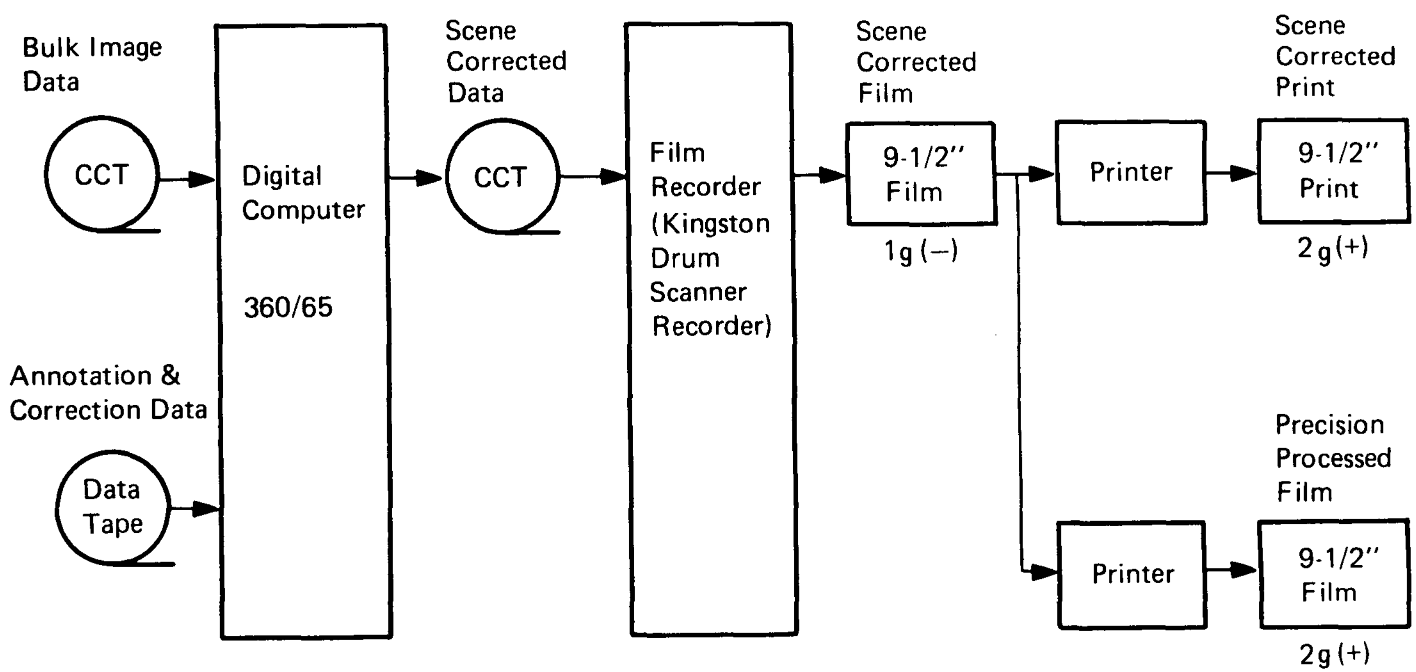


Figure 3. IBM Image Processing Configuration and Data Flow

A summary of the processing steps is shown in Figure 4. It is noted that the MSS sensor data is initially split into four 46-km (25 n.m). strips and spectrally intermixed. This data is formatted into four 185-km images, each in a unique spectral band. These tapes are then processed and the data is corrected, annotated and recorded on large format film, 25 cm (9.5 inch), eliminating a photographic enlargement operation for most applications.

2.2 Experimental Approach

2.2.1 Sensor Errors

The principal errors associated with the data received from the two ERTS sensors are listed in Table 2. These errors are fully described in Reference 2.

Table 2. ERTS Sensor Data Errors

MSS	RBV
Mirror Velocity Panoramic Distortion Scan Skew Earth Rotation S/C Velocity Perspective Projection Attitude Altitude Detector Response	Scanning Raster Distortions Perspective Projection Attitude Altitude Shading

If these sensor errors are to be corrected, they must be either predictable or measurable. Errors due to MSS mirror velocity, panoramic distortion, scan skew, and perspective projection are systematic and stationary. That is, the effects are constant (for all practical purposes) and can be

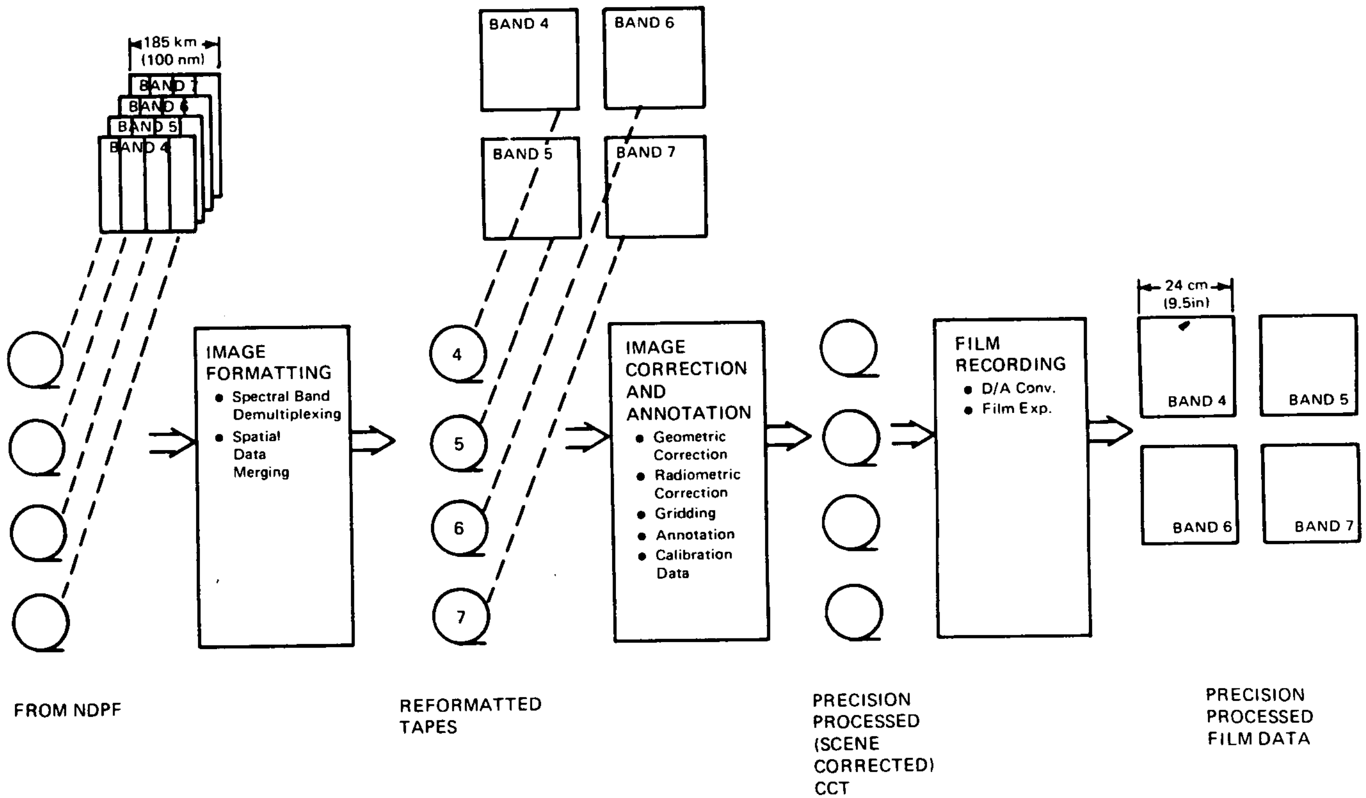


Figure 4. ERTS Image Processing Operations - Digital Processing

predicted in advance. Errors due to spacecraft velocity are a known function of that velocity, which can be obtained from tracking data. Errors due to earth rotation are a function of spacecraft latitude and orbit and thus can also be predicted from tracking data.

Attitude and altitude errors are neither systematic nor stationary. If they are to be corrected, their effects must be measured for each image. The measurement technique used here involves apparent displacements of ground control points (GCP's)--recognizable geographic features whose actual positions are well known. The image locations of the GCP's are determined by application of the Sequential Similarity Detection Algorithm[5,6] to appropriate areas of sensor data. For the MSS, differences between the actual and observed GCP locations are used to evaluate the coefficients of cubic time functions of roll, pitch and yaw and a linear time function of altitude. For the RBV, the GCP locations are used in standard photogrammetric resection equations to determine the attitude and position of the sensor at the moment of exposure.

RBV scanning raster distortions are measured by observing apparent displacements of a 9 x 9 array of reseau marks etched on the faceplate of each tube. The method by which these marks are located in the input data can be explained with reference to Figure 5.

The reseau marks are crosses with arms nominally four samples wide and 32 samples long. They are significantly darker than the surrounding data values. If the data samples in an image area which contains a single reseau are summed by column and row, the sums which correspond to the arms of the reseau will be significantly lower than the surrounding sums. By finding the lowest column or row sum, setting a threshold midway between the lowest sum and the local average sum, noting the sequence of contiguous sums which are below this threshold, and taking the center of the sequence as the center of the arm, the two arms (and hence the "center") of the reseau can be determined. To suppress detection of "false" reseaus, it is required that the sequence of sums below the detection threshold be greater

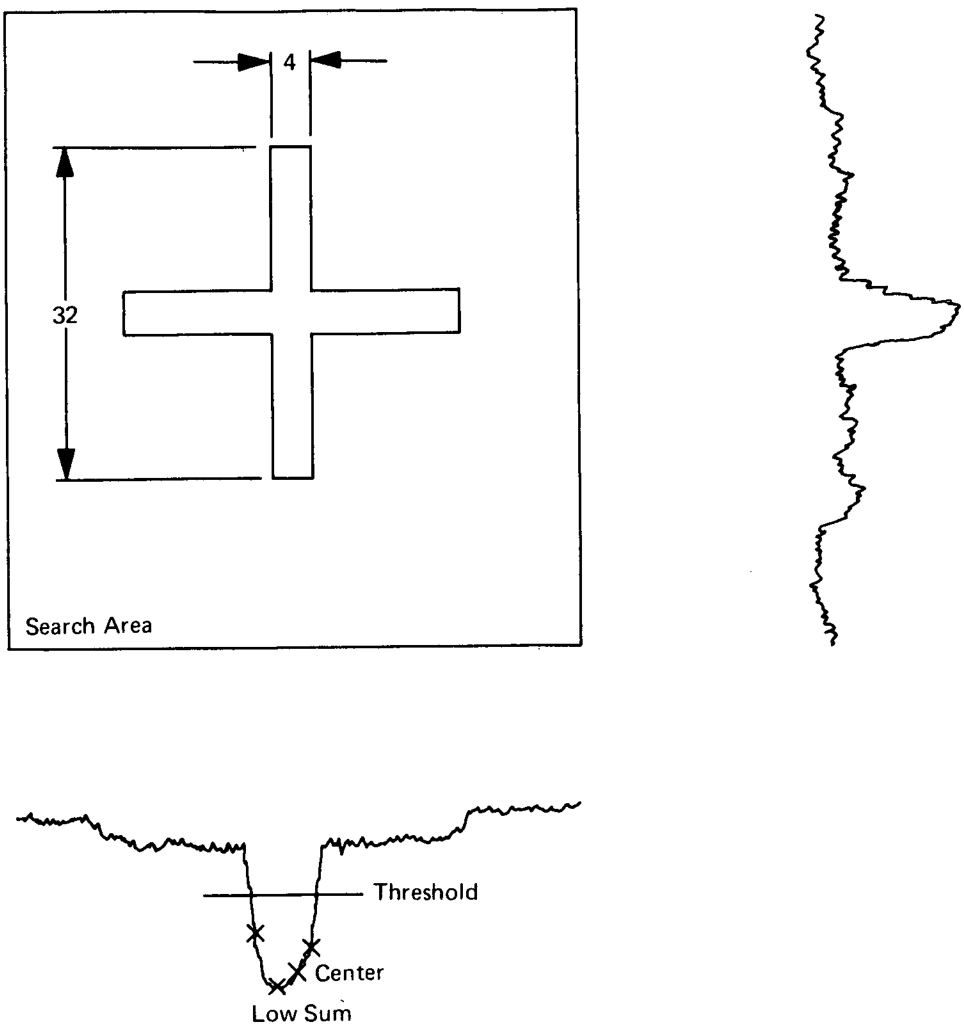


Figure 5. Reseau Detection Approach

than two and less than eight and that the data values of the reseau arms be at least eight counts less than the surrounding data values.

Once the reseau marks are located, the nominal and observed locations are used to evaluate the coefficients of a pair of fifth-degree bivariate polynominals. These polynomials provide a model of the composite effect of the various scanning raster distortions.

Radiometric errors (detector gain and shading) can be corrected only if suitable prelaunch and postlaunch calibration information is available. If such information can be obtained, correction tables which will cause all detectors to have known, equal responses to input radiance and functions which will conpensate for the shading effects of the RBV can be generated.

2.2.2 Geometric Correction

The image spaces and transformations used in the geometric correction of MSS data are shown in Figure 6. The input image is an array of digital data which represents a geometrically distorted one-dimensional perspective projection of some portion of the earth's surface. The output image is a geometrically correct UTM projection of the same ground area.

GCP's are located in the input image and are mapped into the tangent plane using models based on all those errors which can be predicted or determined from tracking data. The nominal GCP locations are mapped from the UTM space to the tangent plane through the equations that relate points in UTM or tangent plane space to points on the earth's surface. The nominal and observed GCP locations in the tangent plane are then used to evaluate the coefficients of the attitude and altitude models.

A network of anchor points spanning the output image is then mapped into the tangent plane and from there (using all the error models) into the input image. Two bivariate polynomials are fit to the two sets of anchor point locations to provide a composite, global mapping from output image to input image.

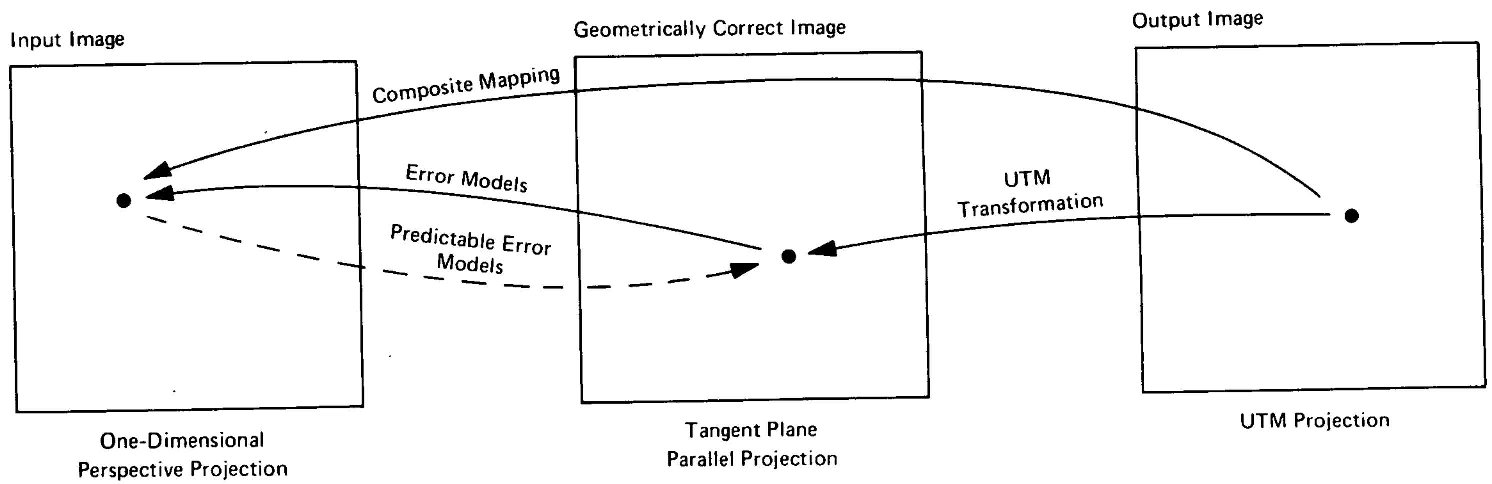


Figure 6. MSS Image Spaces and Transformations

Development of mapping polynomials for RBV geometric correction proceeds along similar lines (see Figure 7). Reseau marks are found in the input image and used to determine the coefficients of polynomials which model scanning raster distortions. GCP's are located in the input image and are transformed to the tangent plane through the scanning raster distortion and perspective projection models. Nominal GCP locations are mapped from the output image to the tangent plane. The nominal and observed GCP locations are then used to determine the attitude and position of the sensor at the moment of exposure. All the mappings are combined to produce a composite output-image-to-input-image mapping in exactly the same manner as for the MSS.

Rather than apply the mapping polynomials to all points of the output image, an interpolation grid is established on the output image. This grid is constructed such that, if the four corner points of any grid mesh are mapped with the mapping polynomials, all points interior to the mesh can be located in the input image with sufficient accuracy by bilinear interpolation on the corner points. This idea is illustrated in Figure 8.

Once an individual output image point has been located in the input image, the situation shown in Figure 9 applies. A data value for point P must be derived from the values at points A, B, C and D. A method currently being implemented is nearest neighbor assignment; i.e., the value of the closest data point (C in this case) is assigned. Bilinear interpolation (or some other resampling algorithm) applied to the surrounding data values to generate a new data value can also be used, but is more expensive computationally.

2.2.3 Radiometric Correction

Radiometric correction for the MSS is a relatively simple matter, if the relationship of desired "corrected" values to received values is known. There are a total of twenty-four detectors on the MSS, each one of which can generate only a small number (64 or 128) of distinct output values. Thus it is quite feasible to define for each detector a table which specifies the desired value for each of the possible detector output values. Radiometric correction can then be accomplished by a simple table look-up operation.

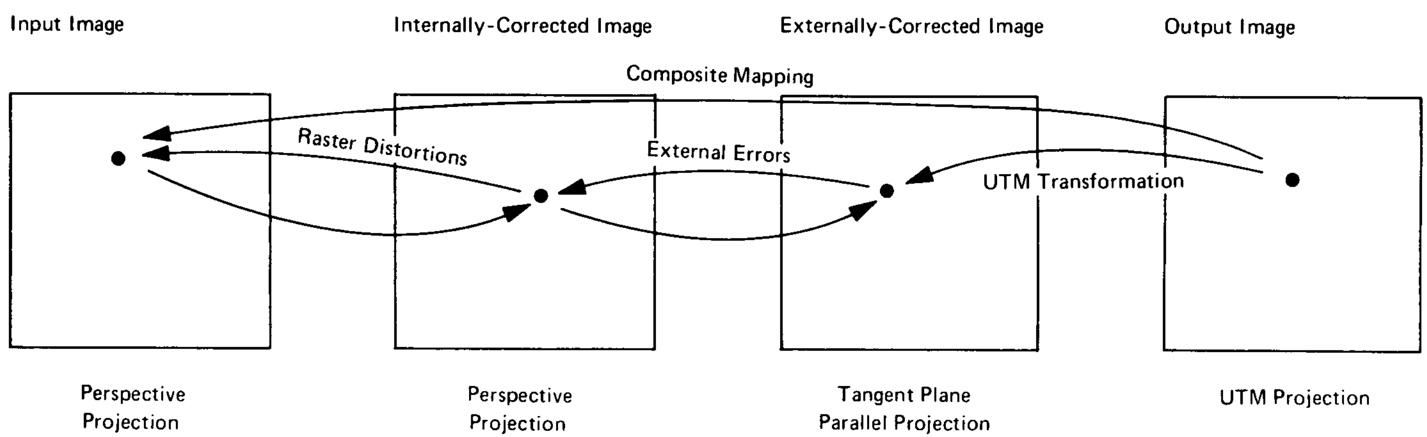


Figure 7. RBV Image Spaces and Transformations

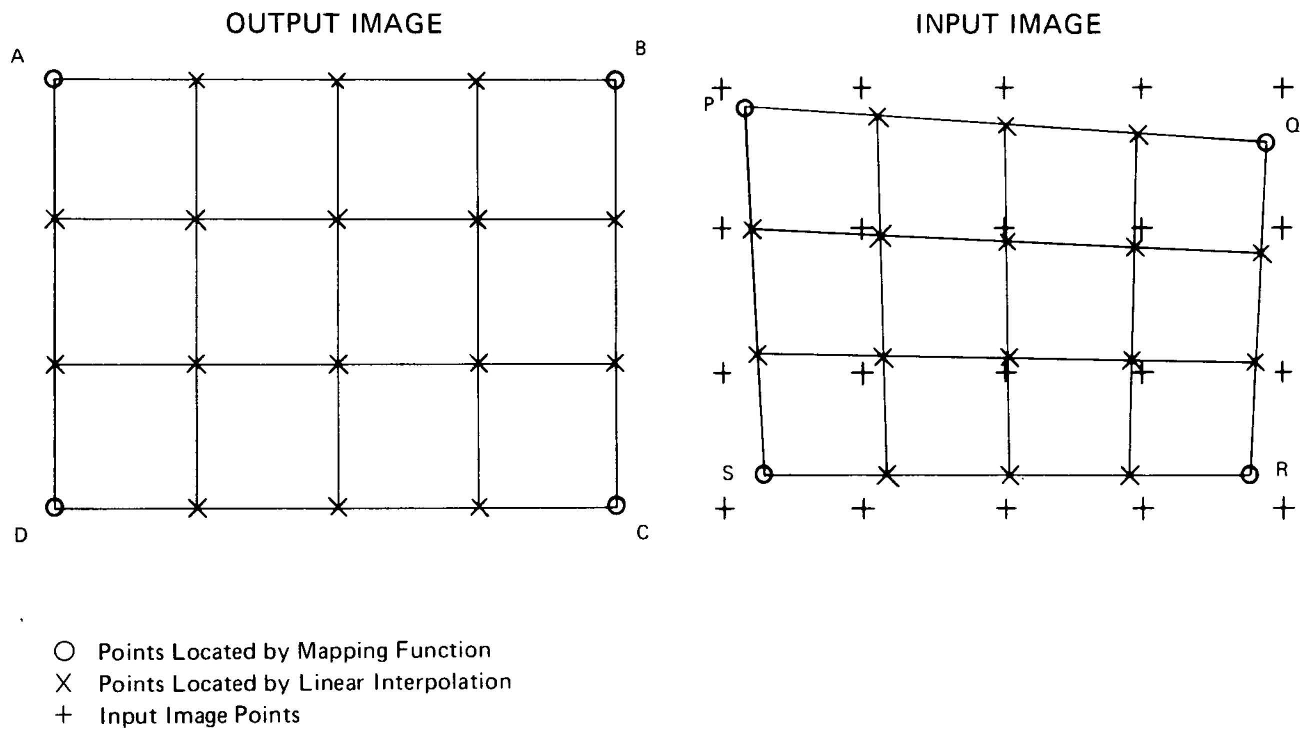
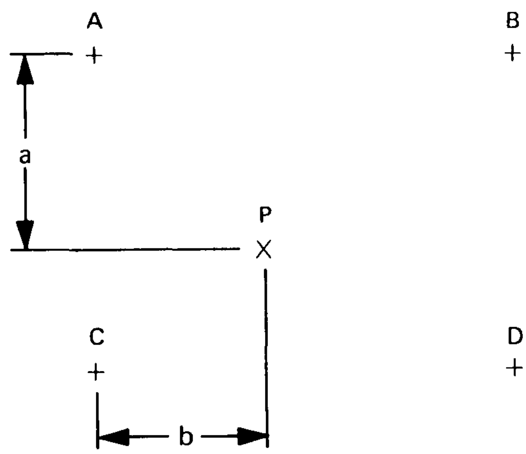


Figure 8. Use of Linear Interpolation in Mapping Operation

DATA VALUE DETERMINATION



NEAREST NEIGHBOR ASSIGNMENT

$$V_P = V_C$$

BILINEAR INTERPOLATION

$$V_P = (1 - b)\left[V_A + a(V_C - V_A)\right] + b\left[V_B + a(V_D - V_B)\right]$$

Figure 9. **Data Value Determination**

Such correction tables can be used to accomplish a variety of objectives. For example, by computing average values of detector outputs in areas of approximately uniform radiance, it is possible to compute gain and bias corrections which will eliminate striping due to differing detector responses. It is also possible to generate tables which will modify the video intensities to emphasize or enhance specific types of features or to match the data values to the characteristics of the recorder and film used.

Radiometric correction of the RBV is a more difficult task due to the spatially varying nature of the response. Figure 10 shows how the response of a typical tube to uniform input radiance varies across the tube face. Prelaunch calibration data are obtained by exposing the tubes to different intensities of uniform input radiance. The tube responses at an 18 x 18 array of points are measured and recorded. From these responses, values of gain and bias to produce uniform outputs at the 324 test points can be determined. If these values are fit with bivariate polynomials, spatially varying gain and bias functions can be determined. From these functions it is possible to define regions or zones of the image over which constant values of gain and bias can be used with acceptably small radiometric error. For each such zone, a unique correction table is defined, and that table is used to correct all points within the zone.

2.2.4 Annotation

The annotation for the IBM precision processed images will be essentially the same as that specified in the Data User's Handbook. The only differences are in the form or position of some of the information.

The Annotation Block will be at the top of the image, instead of on the left side. The gray scale will be at the bottom of the image. The registration marks will be further apart in the horizontal direction. The information in the annotation will be the same on both types of images. Everything else will be essentially the same as in the NASA images.

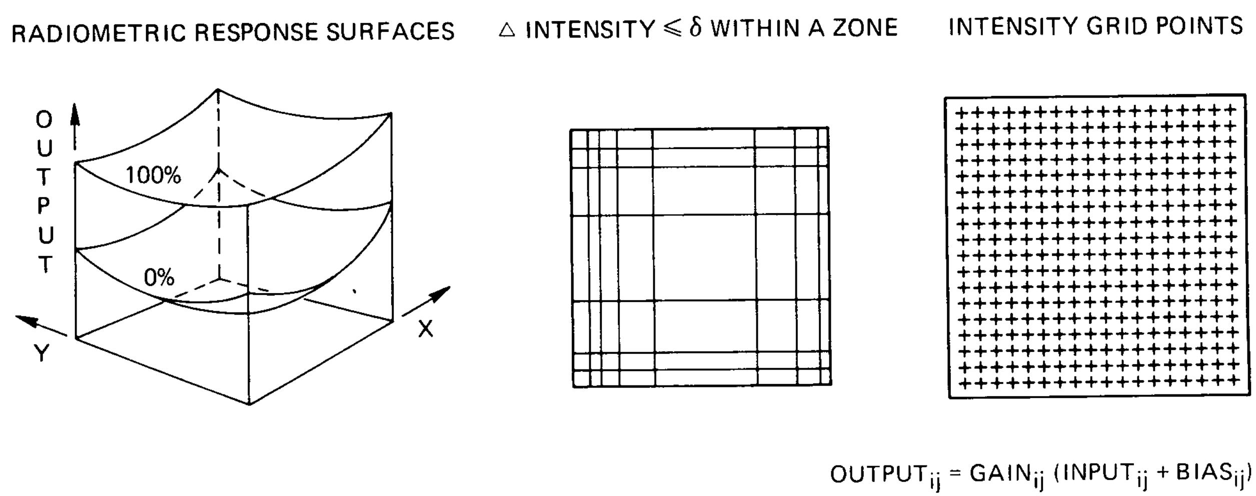


Figure 10. RBV Radiometric Correction

2.3 Technical Results

2.3.1 Reseau Detection/Migration

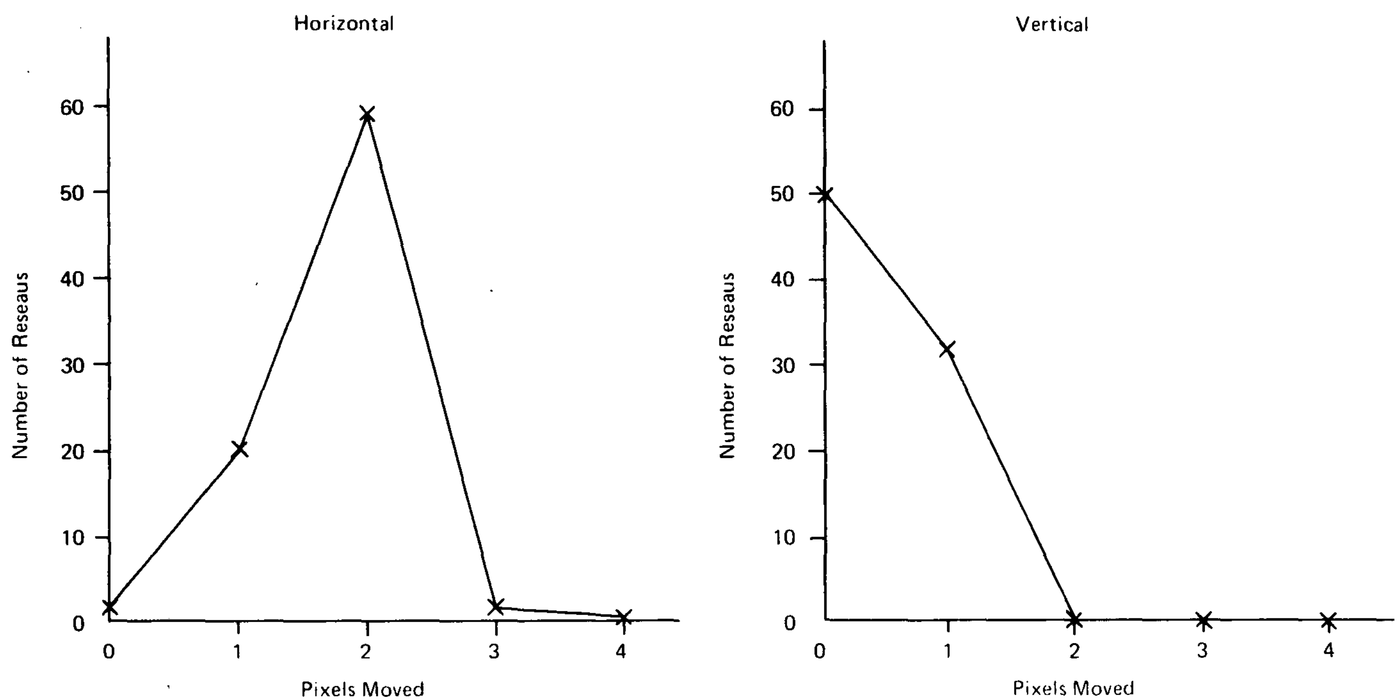
The reseau detection technique was applied to all bands of images E-1002-18134 and E-1014-17375 (which have the greatest temporal separation of RBV scenes received by IBM). Search areas 50 samples square were centered on the expected locations of the 486 reseaus. In all cases, as verified by examination of computer-generated shade prints, the detection technique correctly located the reseau marks. The test was then repeated on 486 image areas picked to contain no reseau. In no case was a false reseau selected.

Band 3 was selected to examine for apparent reseau migration over the twelve-day interval spanned by the two test scenes. Results are shown in Figure 11. In only one case was a migration as large as three pixels in either axis observed. This would seem to imply that RBV internal distortions are quite stationary and that the use of small reseau search areas is justified.

2.3.2 GCP Experimentation

The Sequential Similarity Detection Algorithm (SSDA) has been applied to a variety of targets in several image pairs. The results obtained are summarized in Table 3. Although these results must be considered preliminary, certain trends are emerging:

- Performance (i.e., ability to find the feature and average search time) varies from band to band for different types of GCP's. This suggests that in an operational system, the search for a given GCP should be conducted in that band which has exhibited the best performance on a given type of target.



Scenes Used:	Monterey E-1002-18134-3 25 July 1972	Phoenix E-1014-17375-3 6 August 1972

Figure 11. Reseau Migration

- Strong targets (i.e., those which present a large, distinct pattern) are located quickly. Indistinct targets require much more search time. This is what would be expected from the characteristics of the SSDA.

- When a proper combination of target and band is used, search times are acceptably small. (It should be noted that the search times given in Table 3 show the performance of an experimental FORTRAN program. An operational assembly language program can be expected to be significantly more efficient. Further, no sophistication such as hill-climbing has been added to the basic algorithm.)

2.3.3 Mapping Functions and Accuracies

APL programs have been used to estimate the accuracy of several different approaches to MSS geometric correction. The first approach used the BIAT attitude and altitude data. The second approach used GCP's to evaluate cubic attitude models but took altitude data from the BIAT. The third approach added a linear altitude model which was evaluated using ground control. The fourth approach fit two 6-term polynomials of the form:

$$U = A_1 + A_2Y + A_3Y^2 + A_4Y^3 + A_5X + A_6X^2$$

to the various error models. Results for the four approaches are summarized in Table 4. They show that the use of the BIAT attitude and altitude data is inadequate for precise mapping, GCP's provide significant improvement, and the addition of an altitude model (which increases the GCP requirements by one point) further improves the mapping accuracy. The polynomial fit produces RMS errors that are comparable to the attitude/altitude model combination but maximum errors that are significantly smaller. These results

Table 3. Initial SSDA Results -- MSS Data

Target Type	BAND 4 No. Found/ Tried	BAND 4 Time (Sec)	BAND 5 No. Found/ Tried	BAND 5 Time (Sec)	BAND 6 No. Found/ Tried	BAND 6 Time (Sec)	BAND 7 No. Found/ Tried	BAND 7 Time (Sec)	Temporal Separation/ Location/ Images
1	5/5	46	5/5	29	5/5	4	5/5	15	17 Days
2	1/1	51	1/1	47	1/1	40	1/1	45	Chesapeake
3	2/2	12	2/2	4	2/2	8	2/2	22	Search: E--1062--15190
									Window: E--1079--15140
1	4/8	50	7/21	27	15/21	5	17/21	14	18 Days
3	0/0	-	1/2	9	2/2	11	2/2	27	Chesapeake
4	1/1	50	1/1	29	1/1	7	1/1	29	Search: E--1080--15192
5	0/0	-	16/16	9	15/16	27	14/16	50	Window: E--1062--15190
1	4/6	4	6/6	3	5/6	2	5/6	7	
2	2/8	5	6/8	12	6/8	37	6/8	20	36 Days
3	0/2	-	0/2	-	1/2	48	1/2	7	Phoenix
4	2/3	12	3/3	12	3/3	49	3/3	6	Search: E--1049--17324
6	1/2	5	2/2	6	1/2	5	2/2	52	Window: E--1085--17330
7	1/1	4	1/1	3	0/1	-	0/1	-	
1	1/2	5	2/2	3	2/2	3	2/2	6	72 Days
									Phoenix
									Search: E--1049--17324
									Window: E--1121--17330

TARGET TYPE:
1--LARGE LAND-WATER INTERFACES
2--NON-INTERSTATE HIGHWAYS
3--AIRPORTS
4--SMALL LAND-WATER INTERFACES
5--INTERSTATE-GRADE HIGHWAYS
6--HILLS
7--FIELDS

Note: Times are for 360/65 FORTRAN Program.

Table 4. Predicted Geometric Correction Accuracies

Scene		Mapping Errors in Meters			
		BIAT For Attitude And Altitude	GCP's For Attitude Only	GCP's For Attitude And Altitude	6-Term Polynomial Fit
MONTEREY E-1002-18134 MSS 25 July 1972	Max RMS	1517 999	295 129	115 66	86 52
CHESAPEAKE E-1062-15190 MSS 23 Sept. 1972	Max RMS	1503 722	269 111	202 61	141 68

It should be noted that the accuracies shown in Table 4 are those predicted by APL programs and do not represent measured accuracies of corrected film images. A preliminary version of the MSS correction software (which did not contain all the refinements of the APL programs) was used to correct two MSS scenes. The technique which uses GCP's for attitude errors only was used on scene E-1002-18134 (Monterey, July 25), and the six-term polynomial technique was used on scene E-1062-15190 (Chesapeake, September 23). The corrected images were recorded on film and given to Dr. Robert McEwen of the USGS for evaluation. He reported RMS errors of 188 meters for the Chesapeake scene.

2.3.4 Intensity Modification

Several relatively simple intensity modification experiments were performed on MSS images in order to evaluate the resultant image product in terms of information content and subject quality. Cultural features, such as roads, could be more clearly seen with such an intensity change, and water pollution/sedimentation patterns were enhanced.

film. Cultural features such as roads, could be more clearly seen with such an intensity change, and water pollution/sedimentation patterns were enhanced.

2.3.5 Samples of Precision Processed Images

All bands of the Chesapeake and Monterey scenes referenced in Section 2.3.1 were Scene Corrected and recorded on film. Contact prints of bands 5 and 7 are provided in Figures 12-15. It is noted that good radiometry and resolution are exhibited.

2.3.6 Processing Times

Table 5 shows the current estimated processing times. No attempt has yet been made to minimize processing times, and these times, although reasonable, are expected to be reduced further through the use of better image management, lower processing overhead, and higher I/O speeds. It is significant, however, that the MSS images are each processed in an average CPU time of less than 3 minutes, and an elapsed time of less than 8 minutes.

Table 5. Current Processing Times

<u>RBV Processing</u>

Reseau Detection -- 10 seconds for 81 reseaus

<u>MSS Processing (All 4 Bands)</u>

	CPU (Min)	Clock (Min)
Reformatting	1.7	10
GCP Detection (4 Sec/GCP)	0.8	
Geometric and Radiometric Correction	9.0	20
	11.5	30

Notes:

Computer Used -- 360/65
Clock Times -- Dedicated Computer (Estimated)
Geometric and Radiometric correction (CPU) -- First band 3.0 minutes actual, 9.0 minutes estimated for correcting all four bands.

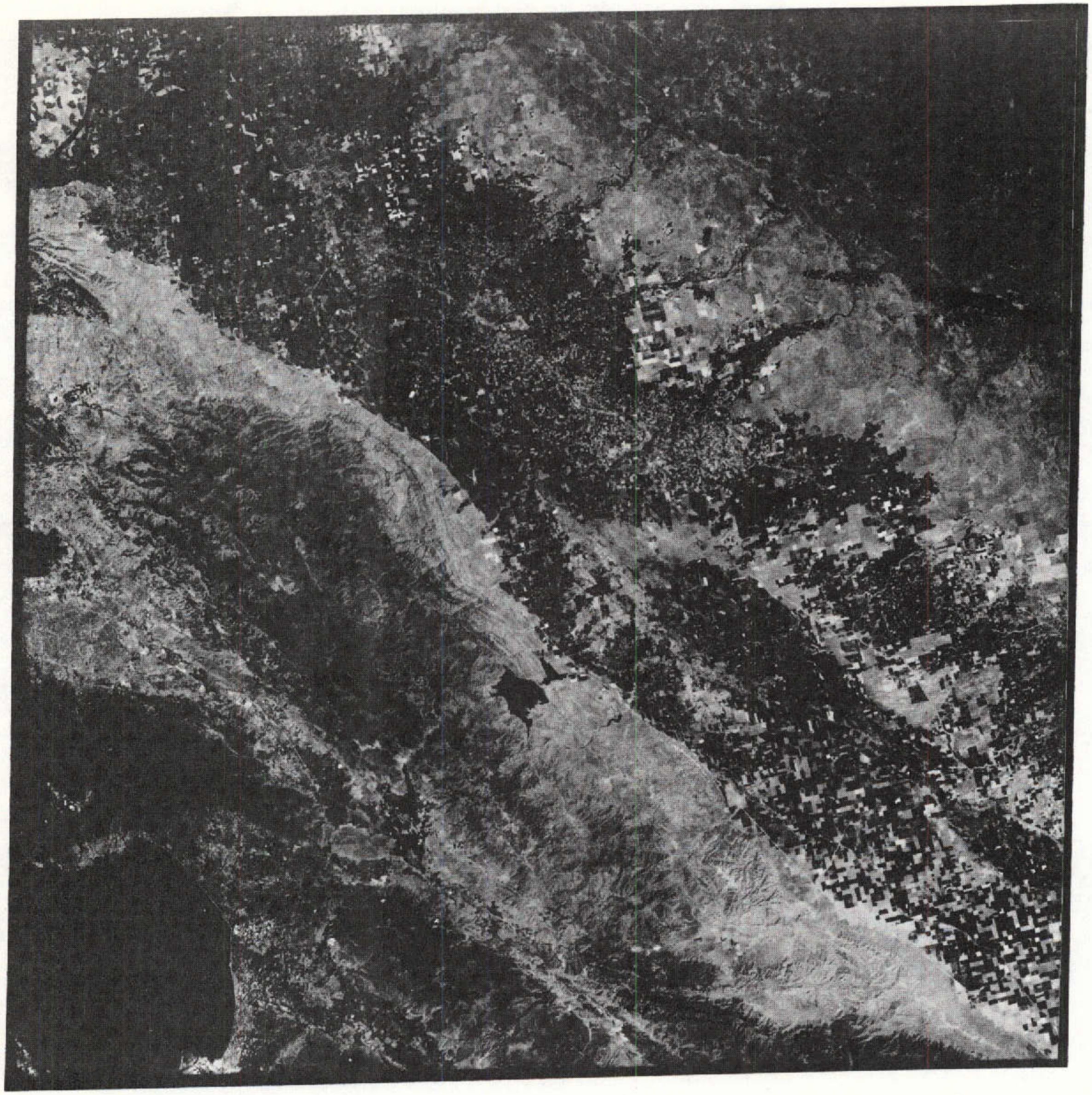


Figure 12. Precision Processed Image E-1002-18134, Band 5

Figure 13. Precision Processed Image E-1002-18134, Band 7

Figure 14. Precision Processed Image E-1062-15190, Band 5

Figure 15. Precision Processed Image E-1062-15190, Band 7

3.0 NEW TECHNOLOGY

No items suitable for reporting under the new technology clause of the contract have been identified thus far.

4.0 PROGRAM FOR THE NEXT REPORTING INTERVAL

The next reporting interval for this project covers the remainder of the contract period. During this interval, all of the contract requirements will be fulfilled. The specific activities planned are described below:

- <u>Completion of Annotation</u>. Design, coding, and testing of the annotation programs will be completed.

- <u>Processing of MSS Images</u>. The MSS geometric and radiometric correction programs will be brought up to the latest design level. The MSS scenes identified in the Data Analysis Plan will be processed with the latest versions of all programs. This processing will require location of ground control points for the scenes. Fully corrected and annotated images will be produced and recorded on film.

- <u>Completion of RBV Programming and Image Processing</u>. The equations and procedures for computing and applying geometric corrections to RBV images will be developed and tested on APL. A sequence of algorithms which can be implemented in the FORTRAN/BAL system will be produced. Algorithms to compute and apply radiometric corrections to RBV images using the techniques of polynomial fitting, zoning, and table look-up will be developed and tested. The algorithms produced in the RBV geometric and radiometric analyses will be coded, tested, and debugged. The latest versions of all RBV correction programs will be used to correct and annotate at least one RBV scene. The resulting images will be recorded on film.

- <u>MSS and RBV Error Analyses</u>. The analysis of errors in the MSS processing will be completed. Results should show the error contributions of the various approximations made as well as the distortions caused by errors in GCP's at various configurations. An error analysis analogous to that performed for the MSS will be performed for the RBV.

- <u>MSS and RBV Image Evaluation by USGS</u>. The corrected MSS and RBV images will be submitted to USGS for an evaluation of their geometric accuracy.

- <u>SSDA Investigation</u>. Available ERTS coverage catalogs and lists of scenes for which CCT's have been received will be examined to select scenes to be used for SSDA evaluation. A list of materials (e.g., catalogs, images, CCT's) required from NASA for past coverage will be generated. Specifications for a standing order for future ERTS products will be generated. Images and CCT's required for SSDA evaluation will be logged in as they are received from NASA. GCP's in various categories will be selected for each our our test sites. Search and window areas representing different seasons and temporal separations will be extracted from the CCT data. The performance of the SSDA in registering these search and window areas will be evaluated.

- <u>Filtering Experiment</u>. Through consultation with those who have been working in this field, an alternative to nearest neighbor assignment and bilinear interpolation for assignment of video values to output image pixels will be selected. An algorithm implementing the selected alternative approach will be developed and tested on small data arrays. This algorithm will be imbedded in the MSS geometric correction routine. At least one of the images referenced under "Processing of MSS Images" above will be reprocessed using bilinear interpolation and the selected alternative approach. The resulting images will be recorded on film. The three versions of each image processed will be compared in terms of image quality.

- <u>System Configuration Analysis</u>. Alternate solutions using special purpose hardware for eliminating image input and output bottlenecks in an operational digital precision processing system will be postulated and examined. Among the options to be examined are higher data rate/density computer compatible tapes; direct digital interfaces to Video Tape, film recorders, and High Density Digital Tape; and peripheral processors.

An operator interactive, display mode of identifying and locating GCP's for initial GCP selection and storage, and also to augment automatic GCP detection and location should the SSDA be unable to locate the necessary number of GCP's in a scene will be examined.

Production support services needed in an operational environment will be examined and possible information management schemes needed to implement these services will be postulated.

The operating system characteristics needed to perform digital precision processing operationally on a general purpose computer will be examined. Virtual storage systems, problems of handling large data sets, and micro-programming techniques will be evaluated.

A conceptual design for a software system to process ERTS-1 image data operationally will be postulated. This design will include a control program philosophy for both RBV and MSS processing; interactive production support; efficient use of channels, memory, and CPU; and checkpoint and other failsafe measures.

Functional system configurations for operational image data processing will be postulated, making interactive use of the above software system design study. Requirements for mass storage, main storage, CPU speed, I/O data rates, displays, and special interfaces will be considered. An operational procedure and a production timeline for film images and CCT's will be postulated. Cost, complexities, schedule implications, etc., of the postulated operational digital precision processing system or systems will be examined. Potential problem areas requiring additional investigation to prove feasibility before implementation will be identified. Typical commercially available IBM product line equipments will be used for cost estimates when possible, to provide "ballpark" estimates of system cost.

5.0 CONCLUSIONS

Although the investigation is incomplete, several preliminary conclusions can be made:

- Preservation of Radiometric Information. Because of the elimination of unnecessary conversions and photographic generations in processing ERTS images by digital image processing techniques, radiometric information is preserved and changed only when correction or enhancement is made. Thus digitally processed images have the potential for System Corrected Radiometry and Scene Corrected geometry.

- Preservation of Resolution. Sensor data is maintained and is simply repositioned to achieve geometric correction. Thus, for the same reasons as above, it is likely that image resolution is not degraded by digital image processing.

- Accurate Mapping. Predictive mapping computation has shown that digitally corrected images can have geometric errors of about 60 meters (RMS). Further investigation is required for a variety of scene types before this preliminary conclusion can be confirmed.

- Operational Feasibility. Digital processing provides a simple and feasible means of changing both the geometry and radiometry of a scene. Changes in sensor performance and characteristics can be compensated for by computer software, and any map projections can be generated by suitable programming and parametric selection.

- *Throughput*. Recent results have shown that four MSS bands can be precision processed in approximately 11.5 minutes of IBM 360/65 CPU time or 30 minutes clock time. This time is comparable with electro-optical processing of ERTS data. Further reduction of these times is projected when an operational system is designed and implemented.

- *Feasible Technology*. Results generated to date suggest the feasibility of digital processing for Scene Correction of ERTS images. Long processing times in the range of hours, which have been previously predicted, have not been borne out. Image quality and resolution are maintained. However, further work is necessary to address existing technical problems and refine techniques.

D

6.0 RECOMMENDATIONS

The preliminary results obtained so far tend to indicate that all-digital techniques present a feasible approach to the correction of geometric and radiometric errors in ERTS images. It is, therefore, recommended that an all-digital correction system capable of modest production capacity be implemented. Such a system should not be expensive to implement or operate but should give ample indications of any problems which might be associated with the use of all-digital techniques in a production environment. The experience gained from the implementation and use of such a system should be quite valuable to the planners of future earth observation missions.

7.0 REFERENCES

1. Bernstein, R. "All-Digital Precision Processing of ERTS Images," IBM Interim Report for Period March - July 1972, prepared for Goddard Space Flight Center, July 1972.

2. Data Users Handbook, NASA-Goddard Space Flight Center, GE Document Number 71SD4249.

3. Colvocoresses, A. P. "Overall Evaluation of ERTS Imagery for Cartographic Application," NASA-CR-129240, November 1972.

4. Bernstein, R., et al. "Experimental ERTS Image Processing," IBM Report CESC-70-0465, May 8, 1970.

5. Bernstein, R. and Silverman, H. "Digital Techniques for Earth Resource Image Data Processing," AIAA Paper, IBM FSC 71-6017, 30 September 1971.

6. Barnea, D. T. and Silverman, H. F. "A Class of Algorithms for Fast Digital Image Registration," IEEE Transactions on Computers, February 1972.